Study on the Modes of Vibration about Langevin Type BaTiO Ceramic Vibrator. (I)

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7. Study on the Modes of Vibration about Langevin Type $BaTiO_3$ Ceramic Vibrator. (I)

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1. INTRODUCTION

Langevin type vibrators using $BaTiO_3$ ceramics have been studied and put to use already. But the important problems about the mode of vibration or the supporting method of vibrator have been left alone, because no suitable means of investigation was found. As the solution of such problems is the urgent necessity for the promotion of practical use of $BaTiO_3$ ceramics, the amplitude distribution and the phase relation of the vibrating surface were measured by a piezoelectric type pick-up in order to obtain some concept about these problems. Fortunately, fairly interesting results were obtained, which will be described here as an interim report.

2. METHOD OF MEASUREMENT

(1) Pick-up

A small pick-up having the construction of Langevin type shown in Fig. 1 (A)

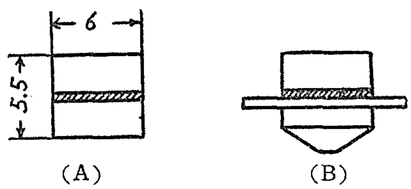

Fig. 1

and consisting of $BaTiO_3$ ceramics and brass was used. It is 6 mm. in diameter, 5.5 mm. in thickness, and the thickness of the ceramic plate is 0.3 mm. The resonant frequency is about 280 kc in the first resonance and about 480 kc in the second resonance. The weight is 1.3 gr. Though the type as shown in Fig. 1 (B) was made and tested, the sensitivity was insufficient. So the pick-up having the type of Fig. 1 (A) was used for the measurement of the following description.

(2) Circuit of Measurement

As is shown in Fig. 2, the out-put of the oscillator OSC was applied to the vib-

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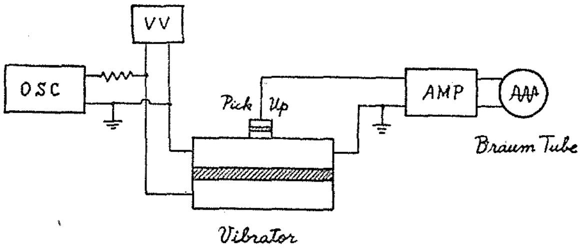

Fig. 2

rator and the amplified out-put of the pick-up was connected to a Braun tube oscilloscope in order to measure its amplitude.

(3) Method of Measurement

Appling the source of about 1 volt to the vibrator, frequency was adjusted to its resonant frequency. In this measurement, the point where the deflection of V.V. was minimum was regarded as the resonant frequency. The measuring surface of the specimen and the contact surface of pick-up were polished into a good plane and a small quantity of oil was used to ensure a good contact. The gain of the amplifier was about 60 db. Amplitude distribution was obtained by changing the position of pick-up and measuring the deflection of Braun tube. For the measurement of curved surface, the contact part of specimen was ground into a plane and measurement was carried out by the same method. For the measurement of the phase relation, two pick-ups of the same form and same characteristics were prepared. Their out-puts were amplified separately, led to the horizontal and the vertical axes of Braun tube respectively, and the phase relation was decided from the figures that appeared on Braun tube.

(4) Preliminary Inspections of the Measuring Method

Preliminary inspections were made because it was doubtful whether an accurate measurement of amplitude distribution was possible by the above method.

(a) In the first place, the pick-up was put on some position of the specimen and the frequency of oscillator was adjusted to its resonant frequency. The out-put was varied by the attenuater of oscillator. The relation between applied voltage to the specimen (reading of valve voltmeter) and the deflection of Braun tube, is shown in Fig. 3. From this result, the relation between the exciting voltage of specimen and the out-put of pick-up can be regarded as linear.

(b) Then, amplitude distribution was measured about a vibrator whose mode of vibration was well-known. The vibrator used here consists of a ceramic plate (80 mm. in diameter, 3 mm. in thickness) and brass plates (80 mm. in diameter, 12 mm. in thickness). When left alone in the air, it generates theoretically the bending vibration in about 15 kc. This vibration is a bending vibration (a transversal wave) having one

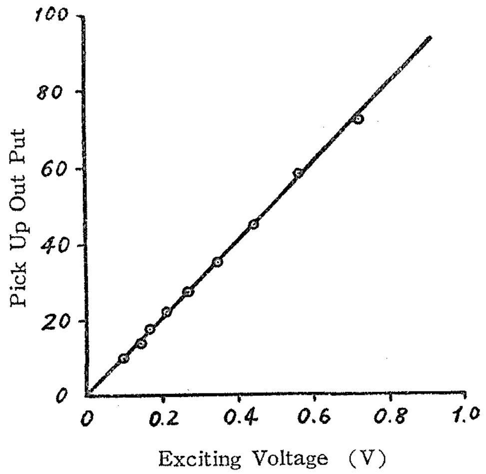

Fig. 3.

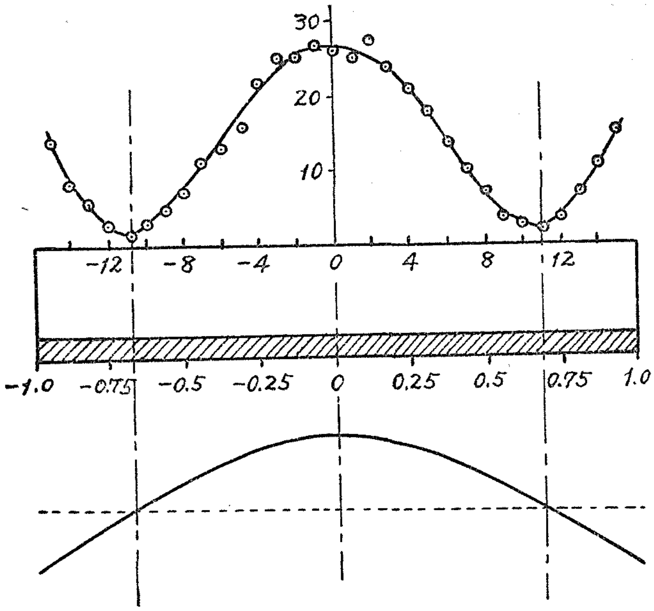

Fig. 4.

nodal circle. The upper curve in Fig. 4 is the measured result about amplitude distribution by the method mentioned above. As the absolute value is measured by this method, its result is considered to be nearly equal to theoretical amplitude distribution (the lower curve in Fig. 4) taking account of the phase relation. As the position of nodal circle perfectly agrees with theoretical value, it is presumed that nearly accurate results about the amplitude distribution can be obtained from such measurement. After these preliminary inspections, measurement was carried out on Langevin type vibrators.

3. RESULT OF MEASUREMENT

(1) Specimen

Four vibrators listed in Table 1 were measured. All specimens are 60 mm. in

Table. 1. Characteristics of specimens.

Specimen	The First Resonance				The Second Resonance			
	f_R	Y_{mo}	Δf	A	f_R	Y_{mo}	Δf	A
SA-60-194	49.5	65.0	0.085	10.5	75.84	55.5	0.14	12.4
SA-60-223	49.45	25.2	0.09	6.7	75.75	21.7	0.19	9.0
SA-60-251	49.65	28.9	0.08	6.8	76.36	36.6	0.18	11.4
SA-60-252	48.96	26.7	0.11	7.6	73.89	19.0	0.23	9.3

diameter, 33 mm. in thickness, 5 mm. in the thickness of ceramic plate. The resonant frequency is about 50 kc. in the first resonance, and about 75 kc. in the second resonance. In Table 1, A is the force factor in 10^7 dynes/e.s.u. volt.

(2) Amplitude Distribution on the Plane Surfaces

As it is presumed that the amplitude distribution on the plane surface is axially symmetric, pick-up was moved along a straight line through the center on the surface

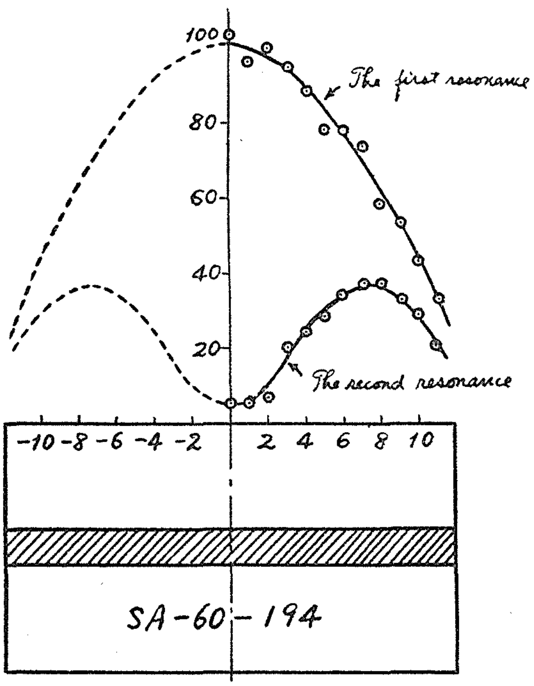

Fig. 5

and the deflection of Braun tube was measured at every 2.5 mm. from center to outside. The measured results about specimen "SA-60-194" are shown in Fig. 5. These results show that no piston motion occurs in the vibration in both resonances. In the first resonance the amplltude is maximum at the center on the plane surface and is smaller at periphery and in the second resonance, the amplitude is maximum at 0.6～0.7 r and is minimum at the center.

In order to inspect whether this tendency is right and the amplitude distribution is axially symmetric, the other three specimens were measured in the same manner as mentioned above. These results are shown in Fig. 6 (A) (B) (C) and all results have

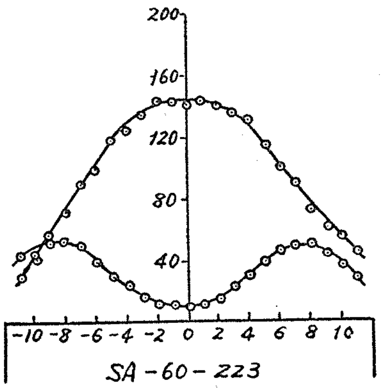

Fig. 6 (A).

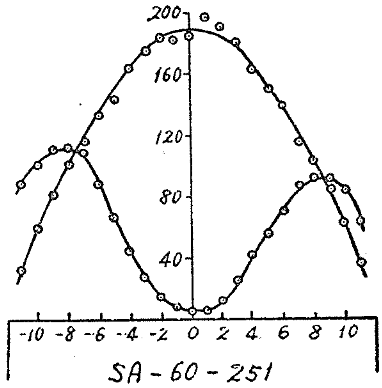

Fig. 6 (B).

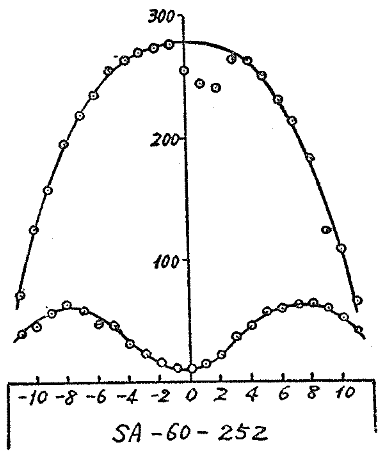

Fig. 6 (C).

the same tendency and axial symmetry. But strictly speaking, some of the results are unsymmetrical, the causes of which seem to be :

(a) The lack of uniformity in piezoelerctic material,

(b) Partial lack of uniformity in adhered state of metal to ceramics.

(c) Irregularity of construction, particularly the hole of a screw bored at one position of the side surface to draw out lead wire.

Above all, the influence of (c) seems to be the largest.

(3) Amplitude Distribution on the Side Surface (Curved Surface)

In order to measure the amplitude distribution on the curved surface, the part of specimen where pick-up contacts, was ground into a plane and the measurement was carried out in a similar manner. One example of the measured results is shown in Fig. 7. The same voltage was applied to the vibrator as is applied in the measurement

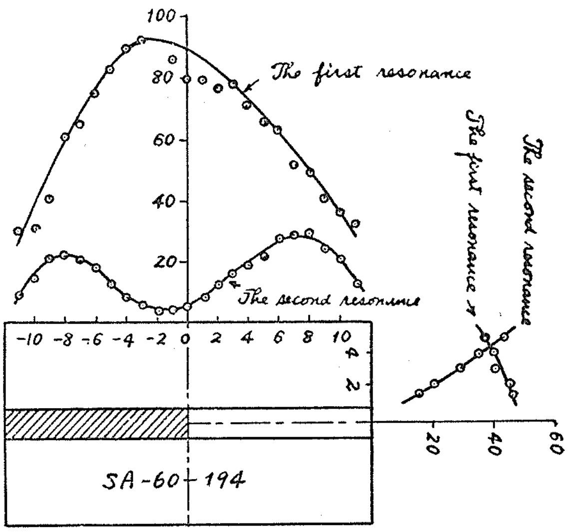

Fig. 7.

of plane surface and this out-put of pick-up was amplified with the same degree. These measured results show that in the first resonance, the amplitude of vibration is very large everywhere on the curved surface and is larger as a given point approaches the ceramic part, and in the second resonance, the amplitude is maximum at the edge far from the ceramic part and decreases quickly toward the center and if measured values are extrapolated, it becomes to zero at the ceramic part. Same tendency was found about the other specimens.

(4) Measurement of Phase Relation

As is explained above, two pick-ups were prepared to investigate the phase relation, the out-puts of which were amplified separately and connected to the horizontal and vertical axes of Braun tube respectively. If the two vibrations are in same phase, the figure on Braun tube is to come to the first and the third quadrants, and if in opposite phase, the second and the fourth quadrants. In the first resonance, it is confirmed that all parts of the plane surface move in same phase. The same result was observed in the second resonance. As to the curved surface, all parts move in the same phase in both resonances. In the first resonance it is clearly shown by the figure on Braun tube that the phase relation is opposite between the plane surface and curved surface, namely, the vibration of thickness direction has the inverse phase compared with that of radial direction. In the second resonance, on the other hand, the vibration of the plane surface has the same phase compared with that of curved surface. These experimental results are summarized in Fig. 8, from which the mode of vibration will be deduced.

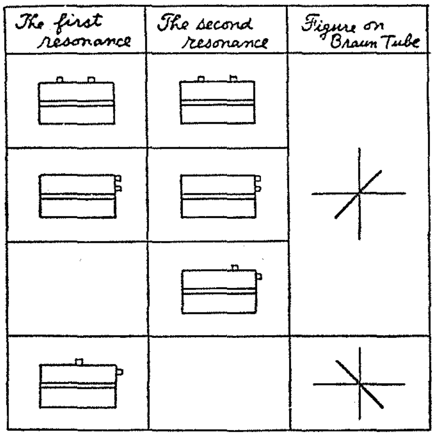

Fig. 8.

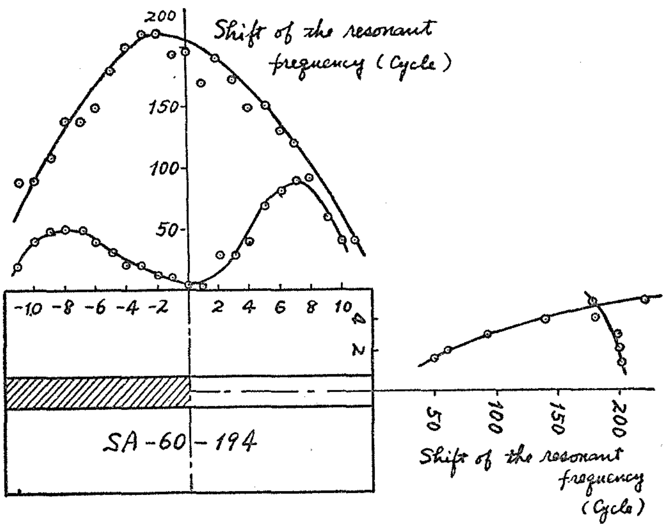

Fig. 9.

(5) Relations between Amplitude, Additional Mass and Resonant Frequency

The resonant frequency of vibrator is reduced by putting the pick-up on the vibrating surface owing to its additional mass. The influence of additional mass on the resonant frequency is small at the point of small amplitude and the larger the amplitude, the larger the influence of additional mass on resonant frequency. In the measurement of amplitude distribution mentioned above, the shift of the resonant frequency owing to its additional mass was adjusted at every measurement. Then, from the values of this frequency shift that was adjusted, the distribution curve was obtained, which is similar to that of amplitude distribution. One of such curves is shown in Fig. 9. The outline of the amplitude distribution will be approximately shown by the measurement of distribution of frequency shift owing to some additional mass.

4. CONSIDERATIONS ABOUT THE EXPERIMENTAL RESULTS

Even if there is some room for question as to whether the measured results are accurate or not, real aspect seems to have been shown by these experimental results. From these experimental results the following items will be deduced :

(1) Conclusion about the Mode of Vibration

From the amplitude distribution curves and phase relations (Figs. 5, 6, 7,8), it will be concluded that the mode of vibration must become such as is shown in Fig. 10.

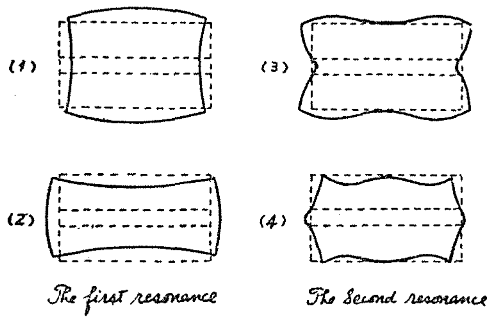

Fig. 10.

According to this conclusion, it is understood that the first resonance has the characteristics of volume constant, and the second resonance has those of volume change even if it is doubtful whether the first resonance strictly has the characteristics of volume constant or not.

(2) Relations with the Theory of Coupled Vibration

The mode of vibration concluded above tallies with the authors' idea about the coupled vibration, according to which, when the vibrations of two modes are coupled, the vibration having higher resonant frequency is always that of volume change (or area change) and the vibration having lower resonant frequency is always that of volume constant (or area constant). A concept about the coupled vibration is illustrated in Fig. 11, where the relations between the resonant frequency and dimension

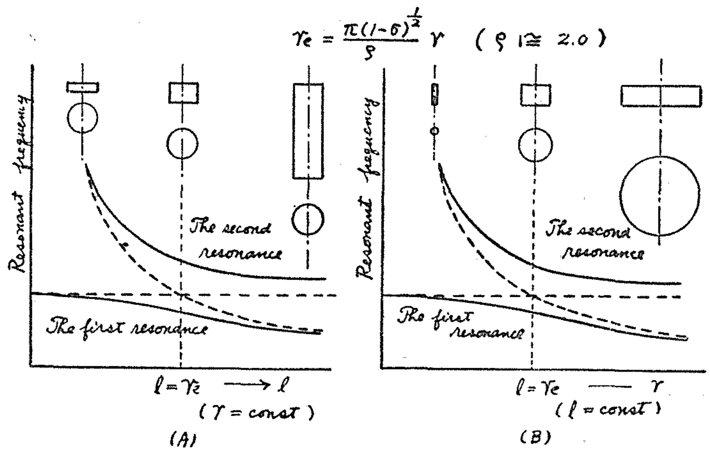

Fig. 11.

(l or r) of cylindrical vibrator are summarized. In both figures, upper curve shows the vibrations of volume change and lower curve, volume constant. In limiting case, they become thickness vibration and radial expansion vibration of wire (namely, the vibration of volume change), and longitudinal length vibration of volume constant.

(3) Relations with the Supporting Method of Vibrator

The vibrators used in this experiment have no proper position to be supported at the first resonance as their surfaces have large amplitude everywhere on plane and curved surfaces. Accordingly, it is concluded that the rubber mould method, in which vibrator is covered with rubber and elastically supported, will be the most proper method. In the second resonance, on the other hand, the surface of vibrator has nodal plane at the position expected from thickness vibration, so it is possible to support by the method such as shown in Fig. 12 (A). The supporting method shown in Fig. 12 (B) is also possible because this vibration has minimum amplitude at the center of upper and lower plane surfaces, and that shown in Fig. 12 (C) is also possible if it is used for the purpose except supersonic radiation.

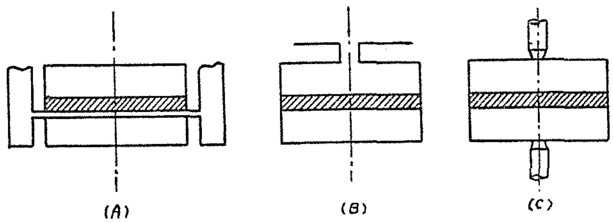

Fig. 12.

(4) Relations with Directional Characteristic

Judging from the measured results, the vibration of the plane surfaces in the first resonance resembles the vibration of circular diaphragm whose edge is supported rather than the motion of piston diaphragm. It is expected that the directional characteristics of the plane surface in the first resonance, have wider angle than that is calculated from the assumption of circular piston diaphragm and have values near the circular diaphragm whose edge is supported. The vibration in the second resonance, on the other hand, has maximum amplitude at about $r_m = 0.7\ r$ and this directional characteristic will be nearly equal to that of the circular radiant body of 0.7 r.

When calculated as the circular piston diaphragm, angle reduced by half becomes approximately

$$\varphi_1 = 30^\circ\ \lambda/d$$

and when calculated as the circular radiant body, it becomes

$$\varphi_2 = 20^\circ\ \lambda/0.7d$$

The value of φ_1 is nearly equal to φ_2 in this case. Consequently, it can be said that the directional characteristics is sharper in the mode of second resonance when the resonant frequency and radius are assumed to be equal.

5. SUMMARY

The above is the experimental study on the mode of vibration about Langevin type vibrator that has already been in actual use. There are many problems that must be investigated further about vibrators of this type, *e.g.* the vibration under acoustic load in practical condition or the vibrations about the vibrators with other constructions or sizes. As fairly excellent results were obtained by this method, it is expected to be useful for analyzing the mode of vibration not only about Langevin type but about other types of vibrators. These experimental studies will be kept on and the result will be reported in Part 2 and subsequnt papers.